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SHIP-HELICOPTER SYSTEM ANALYSIS

R. A. Egen, et al

Battelle Columbus Laboratories

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FINAL REPORT

on

SHIP-HELICOPTER SYSTEM ANALYSIS

to

UNITED STATES COAST GUARD

December 7, 1973

by

R. A. Egen, J. C. Minor, and H. A. Cress

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16. Abstract - The objective of this task was to identify limitations to Coast Guard ship-helicopter (ship/helo) operations on WMEC and WHEC class vessels, and to study possible ways to remove these limitations to increase ship/helo utilization.  A systems-analysis technique was used to identify and describe the interrelationships among the system elements which affect ship/helo operations. Inherent limitations of ships and helicopters are described, as well as possible missions and modes of combined operations. Special consideration is given to the HARPOON, BEARTRAP, and SHAG helicopter rapid-securing and release systems.  The results indicate no current gear and procedural limitations to a generally greater frequency of use of ship/helo teams. Rather a lack of helicopters available for such increased use seems to be the major limitation. However, solving many current gear and procedural problems would improve safety and efficiency. As the frequency of use of the ship/helo team increases, there will be a need for improved helicopter maintenance techniques for lengthy shipboard deployments and may be a need for a rapid-securing system for rough-sea operations			
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PREFACE

This report summarizes the work performed under Task Order No. 8, Contract No. DOT-CG-23223-A from May 16, 1973 to November 30, 1973. The work was performed by Battelle's Columbus Laboratories under the auspices of the United States Coast Guard, with Lieutenant Frank Mittricker serving as program monitor. For Battelle, Mr. A. J. Coyle served as Program Manager.

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## SHIP-HELICOPTER SYSTEM ANALYSIS

by

R. A. Egen, J. C. Minor,  
and H. A. Cress

### INTRODUCTION

The Coast Guard has been involved with the development, evaluation, and use of helicopters for its missions since they became practical aircraft. It now has 70 operational single-engine helicopters (HH-52A's) and 38 twin-engine helicopters (HH-3F's) for use with flight-deck equipped ships.

The idea of operating helicopters from ships' decks was considered with the advent of helicopters. Today, six icebreakers and the eighteen Medium Endurance Cutters (WMEC's) have flight decks designed for the HH-52A's. Twelve High Endurance Cutters (WHEC's) were designed to accommodate the larger HH-3F's.

The Coast Guard has gained considerable experience with ship/ helicopter (ship/helo) operations. This experience has been gained almost exclusively with the HH-52A operating from the WMEC--only occasionally with the HH-52A operating from the WHEC. The WHEC/HH-3F combination is not operational, and little experience with this combination exists.

Despite considerable capabilities and experience, helicopters are infrequently used aboard WHEC and WMEC class ships. To promote greater use, the Coast Guard's Research and Development branch contracted with Battelle to review ship/helo operations to identify limitations to increased use and to evaluate potential improvements in both equipment and procedures. Though a systems study was emphasized, special consideration was to be given to helicopter rapid securing systems.

SUMMARY

The systems study used information and data gathered from the following sources:

(1) Coast Guard operational personnel aboard ships, at air stations, and in district offices (Rescue Coordination Centers, Naval Engineering, etc.)  
Locations included:

- (A) First District
- (B) Seventh District
- (C) Eleventh District
- (D) Twelfth District
- (E) Aviation Training Center

(2) Coast Guard Headquarters, including:

- (A) Research and Development
- (B) Naval Engineering
- (C) Aeronautical Engineering
- (D) Office of Search and Rescue

(3) Others:

- (A) Naval Air Engineering Center (NAEC)
- (B) Demonstrations of two rapid-securing devices at the Naval Air Test Facility (NATF)
- (C) United States representative of Aero-spatiale, manufacturer of the HARPOON rapid-securing system.

A systems-analysis technique was employed in this investigation. To determine how ship/helc utilization could be increased, the elements of the total Coast Guard system were first identified and their inter-relationships defined. Those elements specifically affecting ship/helo operations were chosen and described in detail, including equipment, procedures, and personal preferences. Suspected limitations to combined use of ships and helicopters were described and analyzed, and the following conclusions were drawn.

(1) Inherent Equipment Limitations

(A) Flight Deck Strength--There appear to be no structural limitations to normal operations of the HH-52A on the 210-foot WMEC, and both HH-52A and HH-3F operations on the 378-foot WHEC.

(B) Ship Stability--There appear to be no serious ship-stability problems resulting from the possible ship/helo combinations. The present reluctance seems to be psychological, both on the part of the ships' officers and the naval engineers. The latter seem concerned with worst-case damaged stability, which probably is not applicable to peace-time operations in known waters.

(2) Ship/Helicopter Operations

(A) Possible Modes of Ship/Helo Operations--There are two possible modes. One uses the ship as a temporary air station, with the helicopter deployed on the flight deck to expand the ship's capabilities. The other uses the ship as a mobile supply station, supporting a land-based helicopter operation.

(B) Possible Job Types--Two have been identified for the ship/helo team. Search and Rescue (SAR) operations are potentially more effective by the increased range of rapid response. Patrols are potentially more effective by ease of surveying, rapid apprehension, and deterring potential violators.

(3) Limits to More Effective Ship/Helo Use

(A) Present Limits

- (a) Limited navigational capability on the HH-52A
- (b) Night-lighting problems on both ships
- (c) Lack of an adequate night-horizon reference for the approaching helicopter
- (d) Inadequate flight-deck fire protection
- (e) Too many persons on deck during helicopter operations
- (f) Some pilots' aversion to sea duty
- (g) Lack of available equipment, particularly helicopters and possibly HH-3F inflight refueling gear

(h) Operational ship pitch and roll limits are not presently limiting ship/helo operations

(B) Possible Future Limits

- (a) Helicopter ship-board maintenance. This is not a present limit, but could be a limit to deploying helicopters aboard ships for longer than a month, due to the need for periodic major maintenance
- (b) Lack of a rapid-securing system. This too is not a present limit, but would limit helicopter launching and recovery if operations became necessary on rough seas

ELEMENTS OF THE SYSTEM

The ship/helo team is a tool--one of many available to the Coast Guard for use in its missions. In pursuing the limitations to the increased use of this tool, as well as evaluating potential improvements in equipment and procedures, it became apparent that the issue involves more than the nature of the tool or how it is put together. Such aspects as job requirements, operations planning, and overall equipment inventories and availability are included--aspects that involve all of the Coast Guard's operations. A total operational systems study was beyond the scope of the program. Thus, this report covers that part of the operational system that affects ship/helo operations.

Because of the complexity of the subject, certain major elements were chosen to guide the study, bearing in mind how these elements interrelate. The elements chosen were:

- (1) Ships and Helicopters
- (2) Job Types
- (3) Operational Compatibility Requirements
- (4) Equipment Availability
- (5) Operations Planning.

Figure 1 depicts the ship/helo system and how the elements interact to define ship/helo capabilities and the ship/helo jobs. The arrows indicate the flow of information and sequence of steps. An arrow on both ends of a connecting line indicates a mutual interaction between the elements. The boxes enclose the elements listed above.

The system elements above the dotted line are common to all Coast Guard operations and provide inputs to the ship/helo system. Central to the system is the Operational Compatibility Requirements element. These requirements are formulated from specific types of job requirements, as well as the inherent capabilities and limitations of the ships and helicopters. Though formulated, these requirements will not be met until a decision is made to do so, and this decision will be the result of plans, policies, or priorities established as part of overall job planning. But these interact because the time and costs involved in meeting a requirement can have a decided effect upon overall job plans and priorities.

Thus, a ship/helo tool with certain capabilities and limitations exists which permits certain jobs to be done. These capabilities do not remain static. Changes in the inputs can change them. For example, as noted in Figure 1, experience is an input; as experience accumulates, capabilities are refined and limitations reduced or clarified. Finally, a definition of existing or potential capabilities

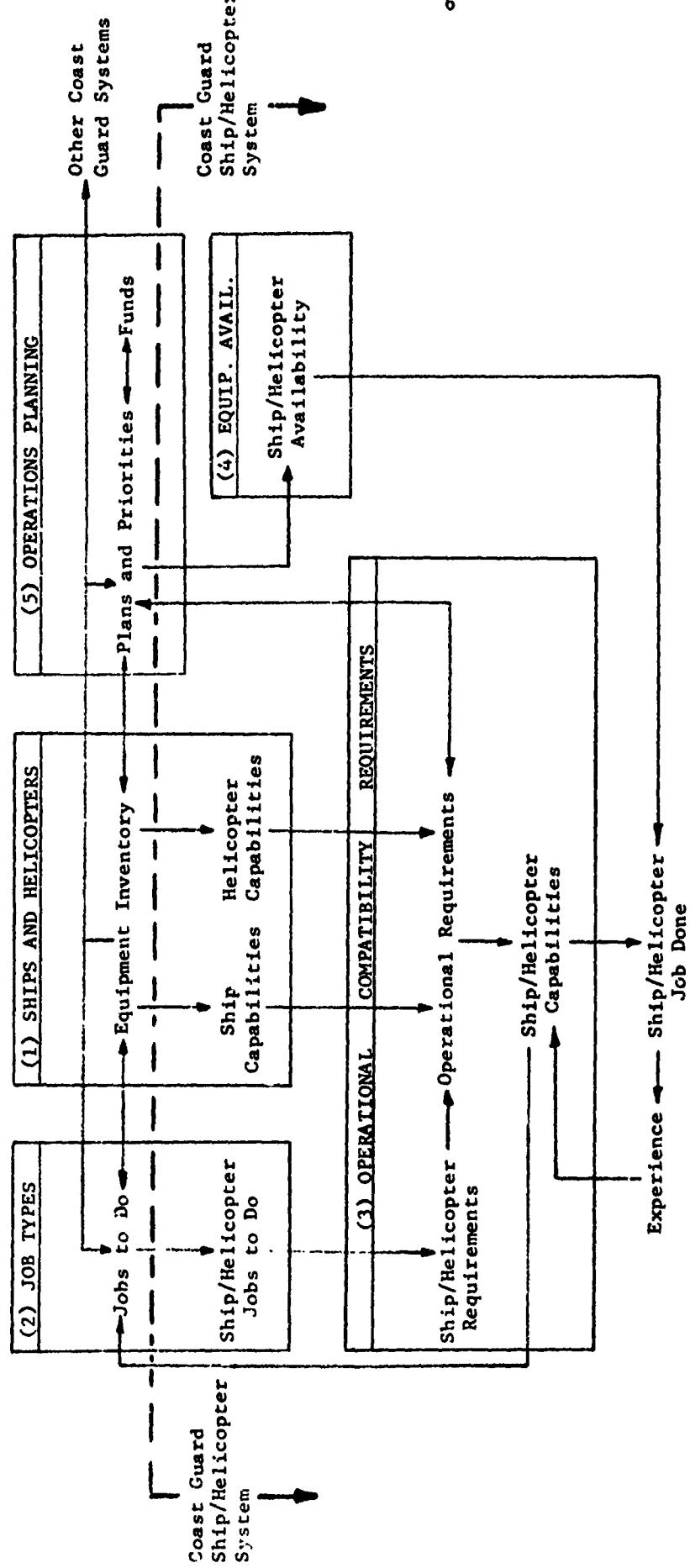


FIGURE 1. MAJOR ELEMENTS OF COAST GUARD OPERATIONS SYSTEM AFFECTING SHIP/HELICOPTER OPERATIONS

and limitations has an effect on what jobs out of all those that need doing might be done with the ship/helo team.

Figure 1 also indicates that certain capabilities are not the only requirement for doing a job. Also needed are ships and helicopters at the right place and time, i.e., equipment availability. This, in turn, depends not just on the total inventory but on planning decisions about availability. These planning decisions involve all Coast Guard operations. The equipment inventory itself depends partly on the jobs to be done and partly on planning decisions.

This brief discussion of Figure 1 illustrates the relationships and the elements involved in ship/helo operations. In the following sections of this report, the major elements listed earlier are discussed from the viewpoint of evaluating limitations to increased use of ship/helo teams. Though presented separately, the interrelationships among these elements should be borne in mind throughout the discussions.

Throughout the remainder of the report, the abbreviations "H52" and "H3" will designate the helicopters of interest. The length designations of the WMEC (210) and WHEC (378) will indicate the ships of interest. The terms "ships" and "helicopters" will refer to these types only.

## HELICOPTERS AND SHIPS

### Relative Characteristics

Ships and helicopters were examined from a systems standpoint to aid in the analysis. The following comparison is drawn.

#### Helicopters

Helicopters are fast and highly maneuverable, with limited load capacity. This results in limited mission time and range because of fuel weight. They are high-performance machines with low margins of structural safety, requiring a high level of maintenance proficiency and frequent attention to ensure reliability.

#### Ships

Ships are slow, with high load capacity, resulting in extensive mission time and range. Helicopter flight decks with adequate space are part of the ship structure. Relative to helicopters, ships are low-performance machines. They require less frequent maintenance, at a lower level of skill to maintain reliability.

### Inherent Limitations

The potential for greater use of the ship/helo team is affected by inherent limitations of both ships and helicopters. These limitations are discussed below.

#### Helicopters

Helicopter range is limited by fuel requirements and pilot fatigue. Nominal range round-trip is 150 NM (nautical miles) at 100 knots for the H52, and 270 NM at 135 knots for the H3. These ranges may be extended somewhat or reduced significantly by changes in the fuel load, aircraft gross weight, or airspeed. However, crew fatigue on both aircraft limits a pilot to about 3 to 4 hours' flying time. This means changing crew if range is to be extended.

An H52 with a normal fuel load may carry 800 pounds, including weight of crew, passengers, and cargo. An H3 with a normal fuel load may carry about 1200 pounds. The external cargo sling on the H52 is rated for a 3000-pound load, while that on the H3 is rated for 8000 pounds. However, the gross weight limitations impose a restriction of about 1500 and 4000 pounds, respectively, with minimum fuel aboard.

Navigational capabilities will be discussed later in detail. Briefly, the H52 is limited to flight about 25 miles from a ship partly because it cannot determine its location accurately. The H3 is equipped

with sophisticated electronic equipment, and has no significant navigational limitations. Finally, with a unique combination of dynamic loads and control inputs--such as when landing--it is possible for the rotor blades of the H3 to contact the cockp't roof. Extreme control movements and landing loads are required to cause this contact, however, making this a remote possibility, particularly if the instructions in CG-419 (paragraph 573.4) are followed.\*

#### Ships

Flight Deck Strength. Coast Guard personnel state that the flight deck on the 210 was designed for the H52, while the flight deck on the 378 was designed for the H3. An examination of the structural configurations indicates that both were built to withstand the landing loads of the H52, and that stringers were added to the 378 deck in the landing area to accommodate the expected H3 loads.

An approximate analysis of the 210's deck strength shows the deck plating to be the critical structural member. It will deform under a 2.5G landing of an H52 at its maximum gross weight (8300 pounds). The 210's deck plating may also just support an H3 somewhat below its maximum gross weight (22,050 pounds) without deforming. A pilot's statement that at least one H3 has been landed aboard a 210 without flight-deck damage supports this conclusion (H3 landings on 210's should be performed only when necessary, and touch-down should be very gentle).

A similar analysis of 378 deck strength reveals no structural problems due to H52 landing loads. The critical structural members are the added stringers in the landing area; they will deform under the main wheel of the H3 during a 2.0G landing at maximum gross weight. The deck plating and stiffener material on both ships is such that failure load is significantly greater than deformation load, providing a generous margin of safety.

Since both analyses were conservative, there appear to be no structural limitations to normal operations of the H52 on the 210, and both H52 and H3 operations on the 378.

Stability. Ship stability--intact or damaged--for the 210 or the 378 with an H52 aboard meets Coast Guard criteria and is adequate. There is concern, however, for the stability of the 378 with an H3 aboard.

The 378 was initially designed to carry an H52. The capability to carry an H3 was a structural design modification of the deck during construction of the first 378. Hull design reflects initial thinking, and Damage Control Books for the 378's show the weight of the H52 in the lists for "normal" and "minimum" operating conditions.

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\* CG-419: Shipboard-Helicopter Operational Procedures Manual, U.S. Coast Guard, Washington, D.C. (December, 1972)

Substituting the weight of the H3 and reevaluating the stability is not appropriate. The 378's have become heavier because of equipment additions, and the Damage Control Books have not been updated. This increase in weight has led them to be rated Status II (no increase in weight or vertical moment is allowed). In discussing the effects of adding 5.3 long tons on the flight deck--the difference between the H3 and the H52--naval engineers indicate this weight would make the 378's marginally stable. There would be no guarantee of stability, even with the best of ballasting techniques.

A number of assumptions are implicit in these statements. First, there are ways to accommodate added weight safely, usually at the expense of performance. There is a great reluctance to trade performance for the ability to land H3's on the 378.

Second, the damage-stability criteria used are reportedly based upon those of the U. S. Navy.\* In this approach, the conditions likely to cause underwater flooding include enemy explosive action. Also, in formulating criteria for adequate damage stability, the ship must remain able to operate (e.g., fire weapons)--not just avoid foundering or capsizing. The distinction between operational and simple survival could significantly affect the question of 378 damage stability with an H3 aboard.

It is not known whether the 378 is rated or evaluated in terms of the U. S. Navy stability criteria; there is some evidence that these criteria have not been applied. Most significantly, the Coast Guard appears to use GM (metacentric height) as a measure of damaged-stability conditions, while the Navy does not. The general inadequacy of GM as a measure of dynamic stability, intact and damaged, has been pointed out.\* Each 378--and possibly each 210--should be examined for current weight data and analyzed in terms of stability criteria--preferably using computerized analysis aids. Each ship must be treated separately because each ship has had different weight modifications.

Another assumption implicit in ship-stability analyses is that all components involved are part of the ship when damage is sustained or sea conditions worsen. A helicopter is not part of the ship; it can usually be jettisoned if necessary to save the ship.

A final assumption involves a "zero-risk" attitude regarding damage stability by the naval engineers who originate the stability limitations. In discussions with the Coast Guard, it became apparent that the minimal probability for damage is recognized by the engineers, but not by the ship commanding officers, and thus is not utilized. This is apparent in the earlier statement that in case of damage, there could be no guarantee of 378 stability with an H3 aboard, even with the best of ballasting techniques.

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\* Sarchin, T.H., and Goldberg, L.L., "Stability and Buoyancy Criteria for U.S. Naval Surface Ships", The Society of Naval Architects and Marine Engineers, Transactions, Vol. 70 (1962)

The lack of such a guarantee should not preclude use of H3's on 378's by informed ship C.O.'s. Most 378's are used where weather histories and navigational hazards are well known, and where information about weather conditions is readily available. Their navigational and detecting gear is exceptional. In view of this, it seems that only an unlikely combination of events would lead to hull damage or loss of ship. The presence of the helicopter aboard might even deter unwise action in time of danger.

#### Modes of Combined Operation

An analysis of the characteristics of ships and helicopters shows that they interact in two basic ways. One way uses the ship as a temporary air station, with the helicopter embarked or deployed on the flight deck. The other uses the ship as a mobile supply station, supporting a land-based helicopter operation where landings are not necessarily required.

#### Ship as Air Station

Using the ship as a temporary air station increases the helicopter's mission time and range at sea, or increases the mission capabilities of the ship through decreased response time and increased inspection capabilities. Helicopter time aboard ship ranges from one day to weeks or more but is limited because the full range of helicopter maintenance and repair personnel and equipment of a land-based air station cannot be duplicated on the ship.

#### Ship as Supply Station

Using the ship as a supply station extends the helicopter's mission time, range, and extent of operations. Perhaps the most important supply function is refueling, but this operation is also used to furnish medical supplies, parts, or repair services.

Refueling or exchanging gear or personnel while hovering precludes the need for the H3 to land, although it can land on either ship in an emergency. Techniques and equipment have yet to be developed for refueling the H52 while hovering; this development would give the H52 a capability similar to the H3 in ship/helo operations. Helicopter Inflight Refueling (HIFR) is usually connected with a land-based helicopter operation. This mode can use either a ship on station or one dispatched to follow the helicopter.

JOB TYPES

Coast Guard jobs combining ships and helicopters fall into two categories: search and rescue (SAR) and patrols.

The important features of these job types are:

(1) SAR:                    - Provides aid in an emergency.  
                                  - Rapid response is almost always essential.  
                                  - Operation time is generally measurable in hours.  
                                  - Location and occurrence are not known in advance (operation cannot be scheduled)

(2) Patrols:                - Provides surveying and policing actions, with a capability for observation, inspection, and apprehension.  
                                  - Although rapid response may be desirable, missions are not classified as emergencies.  
                                  - Time on job is generally measurable in days or weeks.  
                                  - Location is known in advance and encompasses a finite offshore area (operation can be scheduled).

Search and Rescue

Theoretically, the rapid-response nature of SAR missions would appear to preclude ships in favor of helicopters as the craft to use. In practice, however, Rescue Coordination Center (RCC) personnel have a variety of Coast Guard ships and aircraft and Air Force planes available for SAR work. In addition, Navy and merchant ships may be diverted. With such a variety of available aircraft, RCC decisions are based not only upon rapid-response options, but upon the appropriate aircraft (fixed or rotating wing) for the specific case. For example, there have been instances where a helicopter based on a ship on patrol has been used for SAR because it was nearby. Such cases would probably have been handled differently if the ship/helo team had not been in the area.

The nature of SAR missions does not justify the ship-as-an-air-station mode of ship/helo operations. Most SAR cases are within the range of land-based helicopters. Exceptions are handled with fixed-wing aircraft or by diverting commercial or military ships. Since aircraft fuel capacity limits mission time, the use of a ship in the supply-station mode is compatible with SAR jobs.

In recognition of this, the Coast Guard has developed HIFR gear and procedures to refuel the H3 while it hovers close to the ship. Most of the gear is carried by the ship. Possibly because routine H3 landings are not permitted on the 378 and not feasible on the 210, HIFR gear for the H3 was developed first. The layout of the pressurized fuel system or the H3 simplified the development of HIFR. Greater use of HIFR/H3 operations is limited by the lack of fleet-wide shipboard gear. This gear is being manufactured for the Coast Guard, and all ships should be equipped for HIFR with H3's by the end of 1974.

The Coast Guard is conducting an in-house program to study HIFR for H52's also. The layout of this aircraft's unpressurized fuel system presents problems than can be solved only by additions to the fuel system and specialized pressure-control valves for the aircraft end of the refueling hose. Such gear is expected to cost about \$5000 per aircraft.

It is difficult to assess the need for inflight refueling of H52's, for they can land on both ships. Although there are weather conditions when landing is impossible, operational data indicating how often this occurs are not available. Implementation of HIFR for the H52 is not necessary for use of the ship as a supply station, but might increase safety of operation and allow more rapid response for SAR.

In summary, the greatest potential for using a ship/helo combination for SAR jobs lies with the use of a ship as a supply station, primarily for refueling a land-based helicopter. This use is limited by the unavailability of HIFR gear.

#### Patrols

The Coast Guard has a wide variety of patrol jobs, most of which are located well offshore. Those patrols close to shore do not need the ship/helo team.

Patrols are compatible with ship/helo operations where the distance to shore is beyond the range of the H52 or the fuel capacity of the H3. Offshore patrols can be accomplished with ships alone, but the addition of helicopters often increases job proficiency.

Patrols suited to the use of helicopters are the Atlantic Northeast, Pacific Northwest, and Alaska fisheries (Enforcement of Laws and Treaties--ELT); pollution-control efforts in the Gulf of Mexico (Marine Environmental Protection--MEP); and occasional long-distance yacht-race patrols in the Atlantic and Pacific (based on the likelihood of SAR need). Occasionally, patrol-like efforts are needed to provide assistance to the Navy and Air Force.

Experience on fisheries and gear-conflict patrols indicates that the helicopter increases job proficiency. The helicopter permits more rapid fleet survey and easier identification of fish catch and gear.

The speed of the helicopter also prevents the violator from dumping illegal catch or gear to avoid apprehension. Merely the presence of a helicopter far from shore has a deterrent value, for it indicates that a cutter is nearby. The great potential for increasing job proficiency by using helicopters on offshore patrols goes untapped--mainly because of a lack of available helicopters to deploy with the ships.

COMPATIBILITY REQUIREMENTS

Ship/helo operations require detailed consideration of gear, procedures, space, and personnel. Operational areas have been outlined, together with the major factors affecting each area:

<u>Areas</u>	<u>Major Factors</u>
Ship Space	Flight Deck Design, Ship Stability
Flight	Flight Deck Stresses, Communications, Navigation, Procedures, Ship Motion
Securing	Hardware, Dynamic Loads
Servicing (Fueling, Maintenance)	Hardware, Supplies, Accessibility
Human Factors	Space, Duty Limits, Preferences
Safety (All Areas)	Personnel, Material

Because H52's use 210's and 378's as temporary air stations, it is clear that basic compatibility requirements have been met. If plans proceed to provide HIFR gear fleetwide for use with H3's by 1974, the hardware requirements for this operation will have been met. Compatibility requirements for operating H3's from 378's have yet to be met.

Since gear and procedures define operational limits, the major question is: Are present operational limits restricting increased use of the possible combined modes of operation? Except for H3/378 operations, unauthorized partly because of a lack of tie-down fittings, the answer is a qualified "no".

This research has uncovered many problems with equipment and procedures, together with a number of proposed solutions. The problems are secondary limitations to increased ship/helo use, and their solution requires refinement of gear and procedures, sometimes resulting in an extension of the ship/helo operational envelope. However, because the proposed change often eases the task and improves safety, a psychological limitation may be alleviated. It is this psychological factor that affects personal preferences and often leads to a decision not to use the ship/helo team when it might be most effective.

In the sections below, gear-and procedure-related problems are discussed following approximately the outline above. The first area, Ship Space, is a ship characteristic and has been included in the other appropriate areas. The last area, Safety, is also included in the other discussions for convenience.

Flight: EquipmentNavigational Capability (H52)

The limited standard navigational equipment of the H52, plus its single engine (in contrast to the H3, which has two engines), increase the possibility that engine trouble would force it to land in the ocean. Since a ship (particularly a 210) would have a difficult time finding it, an administrative decision has limited the H52 range to 25 miles from a 210 or 378, a distance representative of the range of the ship in about 1 hour. An improvement in the navigational capability of the H52 would remove this limit, probably leading to more effective use of the H52/ship combination. A TACAN unit is known to have been temporarily installed in an H52, enabling use with a 378 for a range far beyond 25 miles; the ship always knew the helicopter's exact location. Universal installation of such equipment seems to be precluded by cost and weight considerations at present.

Miscellaneous Equipment (H52)

There is a general agreement that the pilots' seats are uncomfortable. This, the lack of a relief tube, and comments that pilots cannot get out of their seats without endangering flight control because of the confined situation, have been suggested as reasons why continuous operations of longer than three hours can cause great discomfort and fatigue. This is a limitation of the H52, which might affect combined ship/helo operations. If HIFR for the ... becomes a reality, fatigue problems would increase and crew changes would be necessary. If better seats and relief tubes would make the H52 more comfortable, they would also help ship/helo operations by reducing the need for frequent crew changes.

Night Lighting

Some Landing Signal Officers (LSO's) complain that glare from the lights mounted on the aft edge of the flight deck tend to blind them during night operations. This is a combined problem of deck reflection and the height of the LSO. It might be alleviated by a non-glare surface coating on the flight deck, and a small adjustment to the position of the deck lights. The white landing lights on the helicopter, used to assist the pilot in determining his orientation above the deck, occasionally are directed forward toward the LSO, temporarily blinding him. These lights are controlled from the aircraft, and should be aimed away from him.

Some pilots report difficulty in discerning the LSO against the background and distinct from the flight-deck talker. This complaint could easily be rectified by providing a jumpsuit coated with a material that readily reflects deck lighting. As an example, the 3M product Scotch Light tape might be used.

Artificial Horizon

In the final stages of landing at night, the lighted deck house at the forward end of the flight deck is the most apparent object in the pilot's field of vision, and is used as a horizontal reference when the horizon is obscured. Following a rolling ship can jeopardize a safe landing. An adequate horizon reference is necessary for night use. A bar with colored lights which maintains a horizontal position, visible against the deck house, would improve the safety of the operation. The Canadian Navy has a simple device of this nature on some of its flight-deck-equipped ships. Also, the Coast Guard investigated such a device that was gyro stabilized, using surplus components from an obsolete aircraft. The concept was good but the surplus hardware did not work well because the components were not well suited to the task. Another suggestion is a lighted bar driven by a damped pendulum, similar to a simple ship inclinometer.

Fire-Fighting Equipment

The worst possible accidents during ship/helo operations were judged by Coast Guard personnel to be, in order of decreasing consensus:

- (1) Helicopter striking after edge of flight deck during landing
- (2) Helicopter striking deck house during takeoff
- (3) Helicopter striking deck house during landing.

It is important to note that all these possibilities can result in burning fuel spreading over the flight deck.

A review of fire-fighting capabilities, particularly the placement of personnel and gear on both ships, has revealed a high probability of loss of lives and equipment if a helicopter should crash. The Coast Guard naval engineers are studying this problem. The persons involved indicated an awareness of better gear and methods, and are proceeding with an evaluation of possible installations. For this reason, fire-fighting equipment was not investigated.

Unquestionably, the lack of fire-fighting capability deters ship/helo operations. Skippers and pilots would be more willing to operate under less than-ideal conditions if they had more confidence that their men and craft could cope with any crash situation.

Fire protection during helicopter engine starting is marginal. The gear used to extinguish a hot start engine fire could be improved by lengthening the metallic pipe between the nozzle and the hose enough to reach the engine intakes from the deck. This would eliminate the need to climb up on the sponson to put out an engine fire.

Flight: ProceduresFlight-Deck Jobs

Landings and takeoffs require many of the ship's crew. Possibly some tasks could be combined and some eliminated so there would be fewer persons on or near the flight deck. Safety is the primary consideration here, with efficiency secondary.

In the fire-fighting equipment study being conducted by the Coast Guard, semi-or fully-automatic gear is being evaluated. This gear would reduce the number of men exposed to danger and increase the probability that those in the fire party would survive an accident to fight a subsequent fire.

The LSO and the flight-deck talker are among the most vulnerable persons on the flight deck. If the LSO performed the talker's task, there would be one less person in a highly vulnerable position. Since the LSO is responsible for control of the last phase of landing and at takeoff, combining his tasks with those of the talker by providing him with head- or helmet-mounted gear would permit him to carry out the necessary communications.

Another problem involves the common practice of starting the helicopter engine(s) with ship electrical power. The starter cable is carried to and from storage by several men to avoid chafing its soft covering on the deck. The cable was not studied during this program; however, cables used with mining equipment, with voltage and power capabilities exceeding that needed to start a helicopter, are designed to be dragged through abrasive substances. Cables of this type, made to meet applicable specifications, should be excellent starter cables, eliminating the need for the men who now carry them.

Radio Antenna

Before any flight-deck helicopter operations, the long-wire high-frequency radio antenna extending from mast to fantail on some ships must be lowered. This is another preparatory task, and many ship personnel object to it since it hinders ship-to-shore communications. These communications are not prevented, however, and ship/helo contacts are in no way affected. Four 210's have been issued loop antennas to replace the long-wire, thus eliminating the problem. The Coast Guard schedule calls for eventual retrofit to all cutters of these loop antennas, and also possible whip antennas which do not have to be lowered before ship/helo operations.

SecuringTie-Downs (H52)

The metallic fittings on the H52 tie-down straps tend to corrode and become difficult to operate. This is a maintenance problem and should rarely occur. The devices are simple and small, and keeping them clean and lubricated requires very little time.

Securing Techniques (H52)

According to CG-419, the procedures manual, the operational limits for using the present securing system are  $\pm 10^\circ$  roll and  $\pm 7^\circ$  pitch (ship motion) using a deck grid, and  $\pm 5^\circ$  roll and  $\pm 4^\circ$  pitch if no grid is used.

To determine if these limits prevent greater frequency of use of the ship/helo team, their origin was sought. It is concluded that these criteria derive more from subjective considerations based on experience than from the results of any theoretical/mathematical analysis. This approach is reasonable because it seems to have been (and still is) the only one possible.

Mathematically the securing problem is complex, but can be solved if the motions of the ship and helicopter before landing can be described. But in this case data describing the deck motion spectrum is not available and the problem can only be analyzed for several assumed conditions. A further description of the landing problem is required prior to discussing analytical efforts.

There are three phases to the landing operation. The first begins where the hovering helicopter is clear of any contact with the moving deck and ends ideally with all three wheels touching the deck. The second phase begins with contact and ends when the helicopter is stationary on the deck. The third phase begins at the latter point and ends when the helicopter is tied to the deck.

The first phase is potentially dangerous because any momentary contact while the helicopter is still flying could result in loss of pilot control and a crash into the ship. The time needed for action is the governing factor in this phase and includes the time between deciding to land and moving the controls so that descent begins, and the descent time itself. The latter is the only variable subject to control. The descent time is a minimum with respect to roll at  $0^\circ$  roll. With respect to pitch, the descent time would be shortest at the point of maximum upward pitch, but under these conditions the tailwheel would touch first, with the danger of subsequent uncontrolled forward motion. Hence, the goal is to land at  $0^\circ$  pitch. The decisions during this phase are those of the LSO and the pilot. The pilot can best judge the rolling motion and the LSO the pitching motion.

The second phase involves momentum transfer, or making the motion of the helicopter conform with that of the deck. This requires the application of force to the helicopter, and the present technique is governed by gravity and friction forces with the grid as a backup to prevent gross sliding. The more rapidly the forces are applied, the greater the stresses in the helicopter structure and the greater the chance that the helicopter will slide on the deck. The most critical motion appears to be the athwartships translation component of roll because the helicopter is least stable in this direction. The dangers inherent in this phase are structural damage if the momentum transfer is too rapid, helicopter tipover if the transfer is not effected through all wheels simultaneously, or sliding. This phase usually takes a very short period of time.

In the third phase, the helicopter is initially resting unrestrained (except for the grid) on the moving flight deck. The predominant danger is that with some combinations of roll, pitch, heave, sidewind, and rotor lift, the helicopter will tip over. In this phase then, the governing factor is primarily the magnitude of deck motion.

In the present securing system, the tie-down crew attaches the high tie-down straps during the third phase. It would be obviously dangerous for these men to be under the helicopter during the first two phases. Regardless of how well trained this crew is, there is always the possibility that they will not get the helicopter tied down on the first attempt. Thus it appears that the present roll limit has been chosen to assure that the helicopter will not tip over even if the tie-down is not effected, rather than because of the time it takes to accomplish tie-down. In summary, it appears that the pitch limits derive from possible problems during the first phase, and the roll limits from possible problems during the third phase.

The procedures manual (CG-419) states that "an unrestrained H52 will begin to tip over when subject to a lateral displacement of 15° from the vertical." This statement could not be substantiated. Analysis of the conditions under which an unsecured H52 might tip over due to the motion of a 210 is a complex task, requiring several simplifying assumptions. These assumptions include: (1) Helicopter does not slide, either because of friction or the use of a grid; (2) Effect of helicopter center of gravity not being over the ship's roll axis is small; (3) Ship motion is sinusoidal with a roll period of 9.6 seconds; (4) Effect of changes in helicopter moment of inertia and center of gravity is small. Sikorsky has analyzed this problem\* for the worst case of helicopter alignment where the tail wheel and one main wheel line up and are aligned with the ship's roll axis (helicopter fore-and-aft axis angled at about 19° to the ship centerline). Two gross weights were considered (7000 pounds and 8100 pounds), as well as two values of ship's pitch and heave rate (0.53 g and 0.0 g), and two wind condi-

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\* Sikorsky Aircraft Report SER-62212, "HH-52A Hauldown Rapid Recovery System Operational Test Report", Appendix II, April 30, 1971.

tions (25 knots and 0 knots). Two rotor lift conditions were also considered; 1000 pounds upward lift, representing the thrust produced by the rotor at low collective, and no lift, representing the rotor not turning. This analysis was subsequently extended by Battelle to include all the above conditions when the helicopter fore-and-aft axis is parallel to the ship's roll axis (standard Coast Guard procedure).

The results of these analyses are presented in Table 1, and are quite significant. For the worst case of a low gross-weight helicopter at an angle on the deck with the rotor turning, subject to side wind, pitch and heave, tipover may occur at as little as 6.3 degrees ship roll. However, the tipover angle is very sensitive to helicopter orientation on the flight deck; aligning the helicopter parallel to the ship's fore-and-aft axis changes the tipover angle to 11.3 degrees in this case. At the other end of the spectrum, for ship roll alone, tipover angles of 25.1 and 32.7 degrees are calculated for the two helicopter orientations (aircraft at low gross weight). The tipover angles shown in Table 1 are for information only, and were generated to examine the effect of changing variable conditions. These angles are very approximate, and are not to be used other than to give a general idea of the potential for helicopter tipover. The results do indicate, however, that the present 10-degree operational roll limit is probably valid, particularly since no serious incidents related to ship's pitch or roll have been reported. Thus, though the roll and pitch limits cannot be supported analytically, they cannot be refuted. If Coast Guard personnel are satisfied with these limits, then they must be accepted until either experience or new gear and procedures permits their extension.

Though these limits define the envelope of permissible operating conditions, the real question is whether the limits are deterring increased use of the ship/helo team. In this regard, it is significant that there is little experience with landings and takeoffs at the present  $\pm 10^\circ$  roll and  $\pm 7^\circ$  pitch limits. It is possible that in some cases operations may not have occurred because ship motion was anticipated to be approaching these limits, as during the winter storm season. However, there have been no indications of a helicopter being unable to land on a ship because these limits occurred. Similarly, there appear to have been no cases where a more rapid tie-down system would have allowed an operation to occur which was not permitted by the present criteria. Other factors can also prevent use of the helicopter. For example, pilots and ship officers commonly state that if sea conditions are so bad that a ship's heading cannot be chosen to reduce pitch and roll below these limits, the weather is usually bad enough to prevent helicopter flight operations.

More important is the fact that there are a great many opportunities for ship/helo operations during pitch and roll conditions well within the designated limits which are missed because a helicopter is not deployed aboard the ship, particularly on fisheries patrols in some districts. It appears that ship/helo operations are generally so infrequent because of a lack of available helicopters that the limits

TABLE 1. HELICOPTER TIP-OVER ANGLE; H52 ON 210

Pitch and Heave, g	Side Wind, knot	Rotor Lift, lb	Tip-Over Angle <sup>(1)</sup> , degree
<u>Helicopter Orientation: Angled<sup>(2)</sup>; Gross Weight: 7000 Pounds</u>			
0	0	0	25.1
0	0	1000	21.7
0	25	0	21.0
0.53	0	0	19.3
0	25	1000	17.4
0.53	0	1000	13.5
0.53	25	0	12.3
0.53	25	1000	6.3
<u>Helicopter Orientation: Angled; Gross Weight: 8100 Pounds</u>			
0	0	0	25.3
0	0	1000	22.3
0	25	0	21.6
0.53	0	0	19.5
0	25	1000	18.5
0.53	0	1000	14.4
0.53	25	0	13.4
0.53	25	1000	8.2
<u>Helicopter Orientation: Parallel<sup>(4)</sup>; Gross Weight: 7000 Pounds</u>			
0	0	0	32.7
0	25	0	28.8
0	0	1000	28.4
0.53	0	0	25.7
0	25	1000	24.4
0.53	25	0	19.0
0.53	0	1000	18.3
0.53	25	1000	11.3
<u>Helicopter Orientation: Parallel; Gross Weight: 8100 Pounds</u>			
0	0	0	32.8
0	25	0	29.5
0	0	1000	29.1
0.53	0	0	25.9
0	25	1000	25.7
0.53	25	0	20.1
0.53	0	1000	19.4
0.53	25	1000	13.4

Footnotes appear on the following page.

## FOOTNOTES FOR TABLE 1

- (1) Calculated using method in Sikorsky Aircraft Report No. SER-62212, "HH-52A Hauldown Rapid Recovery System Operational Test Report", Appendix II, April 30, 1971; approximate values only
- (2) Tail wheel and one main wheel line up and are aligned with the ship's roll axis
- (3) Thrust produced by the rotor at low collective
- (4) Helicopter fore-and-aft axis parallel to ship's roll axis

of the present tie-down gear and procedures have yet to be limiting ship/helo use. A rapid-securing system, then, would not by itself lead to an increase in ship/helo operations. Thus, it is concluded that the present operational limits ( $\pm 10^\circ$  roll,  $\pm 7^\circ$  pitch, using grid) are neither limiting current operations in general, nor preventing greater frequency of use of the ship/helo team.

A more rapid tie-down and release system would, however, increase safety at landing and takeoff. The present tie-down system requires four men, two on each side of the flight deck in the nets under the helicopter. A helicopter crash on the flight deck would probably kill or critically injure at least two men immediately. A rapid automatic tie-down and release system that eliminated the need for some of these tie-down men would increase the safety of the operation. However, safety priorities must be established for all those exposed on the flight deck who are vulnerable during a potential crash situation. Possible means to improve safety must be weighed against the funds available and the frequency of the situation.

#### Tie-Downs (H3)

Use of the H3 with the 378 is limited in part by the lack of an acceptable tie-down system. The present low tie-down chains used with the H52 have a limited capacity and might not be capable of resisting high side loads on the H3 on the deck of a rolling ship. In addition, the securing eyes on the H3 main gear are not strong enough to take large fore-and-aft loads. If a combination of high and low tie-downs, as used with the H52 to prevent sliding and tipover, could be adapted to the H3, these limitations would be removed.

Operating the H3 from the 378 would require, at most, a new grid to be used solely with the H3, several new tie-down mushrooms on the flight deck, and high tie-down attachment points on the H3 fuselage. The grid used with the H52 might, however, be modified or moved to accommodate the spacing of the H3 main landing gear. New tie-down mushrooms should be stronger than present ones, to withstand the higher loads from the H3 low tie-downs resulting from ship motion. Although a detailed analysis of the H3 structure was not possible, a visual inspection of the fuselage revealed structural members in the area where high tie-downs would be installed. Therefore, the addition of these fittings appears possible with no serious technical problems. Funding for these fittings, however, must be justified by the need for H3/378 operations.

One further change--replacing present tie-down straps with higher-strength ones suitable for use with both helicopters--would keep inventory to a minimum and eliminate the danger of securing the H3 with straps of inadequate strength.

Rapid Securing Systems

Although a systematic study does not show that the lack of a rapid securing system is presently a major limit to combined ship/helo operations, it may be in the future--either for Coast Guard missions or to permit joint Coast Guard-Navy operations. Thus, the various rapid tie-down systems were studied and evaluated. These are the French HARPOON (SNI Aerospatiale), the Canadian BEARTRAP (Fairey Canada, Ltd.), and the proposed Coast Guard SHAG.

The HARPOON system, developed for the French Navy over the past 10 years, uses a perforated steel disc (approximately 2000 pounds) that is usually installed flush with the flight deck. A gimballed spear (weighing approximately 50 pounds for the H52), consisting of a hydraulic cylinder and a mechanical locking head, is installed in the lower fuselage beneath the helicopter's center of gravity. At touch-down, the pilot triggers the HARPOON, the spear plunges through the disc and locks on, and the cylinder pulls the helicopter securely to the deck to prevent sliding. The present HARPOON system available to handle H52 securing loads has a limit of 15° on the angle of engagement with the disc; the locking fingers will not operate if the HARPOON swings more than 15° from the vertical axis through the helicopter. Only the LSO is exposed on the flight deck during landing and takeoff.

The BEARTRAP system, developed for the Canadian Navy, was evaluated by the Coast Guard in 1969 and, although the system tests were successful, this installation was found to be very costly and complex. In this system, the helicopter hovers above the flight deck and lowers a cable to ship personnel who connect it to a second cable emerging from a 3-foot-square, 12-inch-deep recess in the center of the flight deck. When the connection is secure and ship personnel are clear, a winch below deck applies tension to the cable, which guides the helicopter directly over the recess. At a signal from the LSO, the pilot reduces power, allowing the helicopter to descend to the deck. Two jaws sliding in channels along the sides of the recess close quickly upon a probe protruding from beneath the helicopter and lock it in place.

The major portion of the equipment for the BEARTRAP (approximately 10,600 pounds), including securing device, winch drum, power pack, rope accumulator, and control console, is installed aboard the ship, introducing a significant maintenance requirement. Major ship alterations are necessary. Helicopter equipment includes a probe, hauldown cable, and winch. Control is divided between the ship and the helicopter. This system will also allow ship roll without tie-downs of approximately 15°. Several men are exposed on the flight deck during the critical approach phase of the operation. It is significant to note that the Canadian Navy has only two operational units,

and ship roll during operation is limited to 10°; in tests of their unit, ship roll angles as high as 28° were experienced, resulting in some damage to the helicopter.

The SHAG (Shipboard Helicopter Arresting Gear) concept is a derivation of the system now used to recover fixed-wing aircraft aboard Navy carriers. A stationary wire "trapeze" is attached beneath the helicopter, perhaps on the fittings for the external cargo frame, and a mooring hook travels fore-and-aft in a channel attached to the flight deck. The helicopter follows the normal landing procedure at the LSO's direction. Upon touchdown, the LSO operates the hook so that it moves forward (for the H3) or aft (for the H52) and engages the trapeze. Allowable ship roll without tie-downs is not known. System weight is estimated to be over 5000 pounds, almost entirely for the equipment installed aboard ship. At present, control would be exercised by ship personnel only. Sophistication of this system would include pilot release control, as well as some means of providing a hold-down force.

The HARPOON system has some significant advantages over the other available systems based on the information obtained in this study. Added total weight to both ship and helicopter is likely to be the least of all systems because of the simplicity of the concept. HARPOON is controlled entirely from the helicopter by the pilot, while both BEARTRAP and SHAG require sharing the control function between the ship and the helicopter. BEARTRAP landings require a man out on the flight deck to capture the cable lowered from the hovering helicopter, SHAG may require a mooring hook operator, while HARPOON allows removal of all exposed personnel except LSO and talker.

The problem of keeping the equipment operational is eased with HARPOON, since all high-performance items requiring careful periodic maintenance are installed in the helicopter, which returns frequently to an air station for servicing. In contrast, equipment on the flight deck, such as the BEARTRAP securing device and cable or the SHAG mooring hook and guideway, is exposed constantly to the severe seawater environment and must be ship-maintained. Cost of the HARPOON system, including installation, is considerably less than BEARTRAP, but probably somewhat more than SHAG. HARPOON hardware may be obtained virtually off-the-shelf and is proved by years of in-service operation, while SHAG is still in the conceptual stage, requiring both time and money for development and design.

It is of value to review these systems in light of the three phases in the final landing process. No system would reduce or eliminate the dangers inherent in the first phase, i.e., transition from a clear hover position to contact with the deck. In this regard, determining whether operational pitch limits would change requires much greater analysis. BEARTRAP and HARPOON are effectively devices which aid in the transfer of momentum by providing either additional downward load or some

side restraint. While SHAG is also intended to aid momentum transfer, this would require very rapid actuation.

While these systems tend to combine the momentum transfer and tie-down operations, it should be noted that BEARTRAP and HARPOON will secure only to about 15° roll without additional tie-down. Tie-down straps and procedures for attachment similar to those used for the H52 would apparently still be necessary although somewhat greater operational roll conditions would be acceptable. Unless such mechanical systems could be designed to act alone as the securing system, it appears that there is still a limit to allowable roll conditions because of the need to send men on deck to attach tie-downs.

#### Maintenance

A significant objection to ship deployments with helicopters aboard has been the problem of maintenance. This problem may be divided into two major headings: maintenance requirements caused by the at-sea environment, and the difficulties of maintaining a helicopter aboard a ship.

Helicopter maintenance requirements increase aboard ship due to exposure to the hostile seawater environment which can cause accelerated corrosion of engine(s), flight controls, tail rotor assembly, airframe and skin, and rotor blades. The corrosion rate is further intensified if "green water" is being taken aboard during rough weather. Corrosion of flight controls and tail rotor assembly can lead to malfunctioning and loss of aircraft control. Airframe and fuselage skin corrosion shortens the usable life of the helicopter. Corrosion has been found recently in the rotor blade spar-to-pocket bonding area on a helicopter deployed for Alaska fisheries patrols (ALPAT). All of these components require increased preventive maintenance during shipboard helicopter deployment, as detailed in CG-419. It should be noted that no increased electrical-component servicing has been necessary.

Ship vibration and dynamic motion can cause increased helicopter component wear. Specific areas of increased wear include flight controls, landing gear, and rotor blades (when folded). Control cables may work over sheaves or contact helicopter structural members, causing fatigue and wear. If the helicopter is not tied down hard, landing-gear oleo struts will work up and down, possibly causing accelerated wear in the seals (a particular problem with the H3 nose gear assembly). Rotor-blade movement may be somewhat limited through the use of blade "boots"; however, blade flex will still be significant when ship motion is severe. In the past, damage to blades and fuselage structure has been found when the blades were folded, even in some cases when secured with the blade saddle (H52). Wear damage is often more difficult to detect or prevent than corrosion.

There are many areas of maintenance which are made more difficult when a helicopter is deployed aboard a 210 or 378. First, as most

maintenance requires a stable work platform, ship motion sometimes precludes servicing during rough weather. However, rough weather also curtails flight operations, limiting flight hours and the consequent maintenance.

Second, corrosion prevention requires frequent (sometimes daily) fresh-water washdown of the helicopter, particularly of the turbine engine(s). Fresh-water supplies aboard ship are limited, especially on the 210, but in most cases enough is available for aircraft maintenance needs. The 378 has a seawater evaporator, which removes the fresh-water limitation.

Third, helicopter procedures call for minor maintenance every 10 flight hours and major maintenance every 80 flight hours. Space aboard both ships is lacking for any large supply of spares and maintenance material, allowing only enough supplies to carry out the 10-hour routine. Finally, helicopter accessibility is reduced because of the exposed position on the flight deck and the reluctance to attempt major work under this condition.

It has been said that the tail rotor on the H52 cannot be serviced because it overhangs the aft part of the flight deck. However, as CG-419 points out (paragraph 823.1), there is room aboard both cutters either to land the helicopter far enough forward, or to move it. While the large buffer distance for the H3 on the 378 does not allow it to land far enough forward, there is still space enough to move it to reach the tail rotor for maintenance.

The potential for success of extended deployment of helicopters aboard ships is perhaps best illustrated by the experience with Coast Guard icebreakers. Icebreakers normally deploy with two helicopters for periods of from 4 to 6 months. There is enough space aboard to carry those materials necessary for major maintenance. There is also a telescoping hangar to provide shelter from salt spray and to allow helicopter accessibility. Although 210's and 378's do not have these advantages, this experience shows that maintenance requirements do not by themselves rule out successful long-term helicopter deployment in a salt-water environment.

In summary, there appear to be no serious limitations to normal helicopter maintenance aboard ship for about 20 days. The experience on the ALPAT deployments is a good indicator of what can and cannot be done aboard the 210's and 378's. Assuming that the helicopter is adequately prepared before departure (thorough wash and wax and preventive maintenance), and assuming the availability of fresh water, occasional calm days, and a supply of maintenance materials, it is possible to carry out the 10-flight-hour schedule of servicing for some time without impairing helicopter readiness. It is not, however, possible to perform the 80-flight-hour servicing. Coast Guard data indicate that for ALPAT, 80 flight hours are accrued in about 63 days. Due to the minimal ship/helo ALPAT patrol experience, helicopter deployments aboard both ships are

now limited to about 20 days and usually only in good weather seasons. There are no serious limitations to normal maintenance under those conditions.

A recent ALPAT deployment illustrates the need for improved maintenance and protective techniques if ship/helo patrols are to be extended to seasons of bad weather and rough seas. The helicopter in this case suffered heavy corrosion because the conditions were severe enough for over a week that no one could go on deck for servicing. It is reported that the ship was rolling to 40° and that the rotor blades were being dipped into the wave tops at times. The experience might have been prevented if the helicopter had been flown from the ship to a land station before bad weather developed. At the very least, the rotor blades should have been folded to avoid immersion in wave tops. Nonetheless, situations similar to this might call for more protection of the helicopter from the elements during ship/helo deployments in bad weather seasons.

#### Human Factors

Some Coast Guard airmen dislike sea duty because they become seasick and do not like extended periods away from home. Although seasickness and its medication prevent flying, the limitation is temporary because most persons acquire some degree of immunity to ship motion after a few days.

A dislike of sea duty can mean the difference between a "can do" and an "if I have to" attitude in performing ship/helo operations. This dislike limits increased use of ship-based helicopters and can result in exaggerated complaints about the difficulties of proper maintenance. This dislike should also be recognized when operationally limiting "problems" are advanced in terms of gear or procedural difficulties.

EQUIPMENT AVAILABILITY AND PLANNING

There is a potential for greater use of ship-based helicopters on patrols and patrol-like missions. Though personal preferences and some gear and procedural problems deter increased use, the greatest deterrent seems to be the lack of helicopters available for this work. For example, First District fisheries patrols have used a helicopter only once this year (through August), because an H52 was assigned this duty only once so far this year. Assignment of available equipment is a planning function, and may be at the heart of problems related to increased use of the ship/helo combination.

The frequency and mix of SAR and patrol jobs vary from district to district. All districts have SAR jobs, but the patrols are concentrated in the Atlantic Northeast, the Gulf of Mexico, and the Pacific Northwest and Alaskan waters. Perhaps because of this distribution of job types, helicopters are generally assigned to specific air stations, whereas the ships are often sent interdistrict to a place of need. This may reflect an assumption that helicopters are to be used for SAR, and ships for patrols. Possibly a reevaluation of jobs by district could result in the reassignment of some helicopters to other districts for use on patrols. Perhaps, too, aircraft could be temporarily reassigned or sent interdistrict as needed for patrols.

Although a rapid tie-down system and HIFR or improved navigation gear can be installed on H52's, this equipment is difficult to justify now on the basis of job need. Job needs have been examined from the standpoint of how they lead to requirements for gear and procedures to allow ship/helo operations. The planning aspects of the ship/helo combination--whether patrol jobs need a ship-based helicopter or whether such jobs might be done effectively with fixed-wing aircraft--have not been examined.

For example, state-of-the-art high-resolution photographic equipment, mounted on fixed-wing aircraft and operated by a National Marine Fisheries Service agent, might frequently function as effectively as a helicopter, considering the effort necessary for helicopter deployment. In some districts, a land-based H3 might be used on some patrol jobs with a 210 or 378 as a mobile supply station. Discussions with Coast Guard personnel lead to the conclusion that these alternate possibilities have not been carefully reviewed. This is a question of planning, and was beyond the scope of this research.

A definitive planning job is needed, to be updated periodically. All missions requiring 210's, 378's, H52's, and H3's should be studied by reviewing the tasks involved, their goals, and possible means of accomplishment. This should be done with little reference to present operational techniques. District-by-district data are needed about the frequency of each job, with annual and seasonal trends.

Next, the Coast Guard inventory of ships and aircraft should be described in terms of capabilities and limitations, with possible solutions to these limitations. Operating costs for each kind of craft should be listed, and equipment and tasks compared on the basis of unit operating costs, time-in-use, or both. The results would indicate equipment availability and the steps necessary to carry out the Coast Guard tasks in the most effective manner. This process may be programmed for a computer, and should be rerun periodically as missions or available data change. This process would indicate the need for new equipment or procedures, and would produce a quantitative and systems-related base for requesting Congressional operating funds.

An example where the planning task must precede action is the case of mothballed H52's. Eighteen of the 78 H52's are in storage. Nine of these could be made available for patrols if funds were available. Justifying this expenditure, however, requires proof that all available helicopters are being used effectively full time--and that the patrol requires the use of a helicopter. The planning task would provide a means of quickly determining the answers to these questions.

RECOMMENDATIONS

This research has led to several recommendations for increasing the use of the ship/helo team concept. These are, in summary:

- (1) To increase safety and add to the range of action, the HIFR equipment developed for the H3 should be made available to all 210's and 378's as soon as possible. This move would apply primarily to SAR capability.
- (2) For the same reasons, HIFR equipment should be developed and implemented for the H52 (some effort has already been made in this area), if the cost can be justified on the basis of SAR needs.
- (3) All H3's should be equipped with high tie-downs, and new higher-strength tie-down mushrooms placed on the 378 flight deck. H3/378 operational training should begin concurrently with equipment changes. Although the roll and pitch limits of 10° and 7° will probably be adequate for the H3, a rigorous analysis should be performed to confirm this.
- (4) Aircraft (H52's, or H3's on 378's) should be made available to patrols whenever it is determined that their capabilities will contribute significantly to the success of the mission. Since aircraft must be ready at air stations for SAR missions, patrol aircraft may have to be taken from storage. A study of aircraft utilization as a planning tool may reveal helicopters that can be lent interdistrict for patrol work.
- (5) Ship stability should be examined on a per-ship basis as a first step toward determining the real effects of H3 operations. The next and most important step would be careful review of the damaged-stability criteria which lead to the limitations on weight and moment changes, particularly with reference to damage probability during peacetime operations. The results might remove an obstacle to routine use of the H3 aboard the 378.

- (6) A definitive planning task is needed to assure the efficient use of available equipment and personnel for the many jobs that must be done. Prerequisites include the careful gathering of data pertaining to job frequency and location, and the definition of the aircraft and ships in terms of specific capabilities and limitations. The results of this planning would allow more effective ship/helo team operations.

In addition, several improvements in equipment and procedures would aid present jobs and increase safety:

- (1) Improved fire-fighting capability (under study by the Coast Guard). The primary advantage would be increased ability to contain a post-crash fire. A secondary advantage would be fewer men exposed to danger during helicopter operations.
- (2) Installation of bilge keels on 378's. This would increase dynamic stability by increasing roll period and possibly reducing maximum roll angles. Flight operations might then be extended.
- (3) Lighted bar for night-time horizon reference. A low-power, low-cost device should be possible which would result in improved safety during night operations.
- (4) Improved night lighting. Adjustable after-deck lights, flat deck paint with luminescent markings, and contrasting reflectorized or lighted LSO jumpsuit would improve visual reference for pilot and help LSO see at night.
- (5) Improved navigation equipment. DME or TACAN for ships and helicopters might extend the helicopter's range, particularly during H52/210 operations, for each would always know the location of the other. Improved ship's radar might also serve the same purpose.
- (6) Improved helo-ship's bridge-flight deck communications. The possibility of eliminating the flight-deck talker and providing communications equipment to the LSO should be studied, both to improve control safety and to reduce the number of men on the flight deck.

Finally, the following long-range considerations are recommended:

- (1) A rapid-securing system, such as HARPOON, could allow the extension of helicopter operations to sea conditions where ship roll and pitch exceeds the present 10° and 7° limits, while improving the safety of operations by reducing the number of men on the flight deck.
- (2) A study of the maintenance requirements for helicopters deployed aboard ship could lead to a method of performing major maintenance during lengthy patrols that would remove the necessity for the helicopter to return frequently to an air station.